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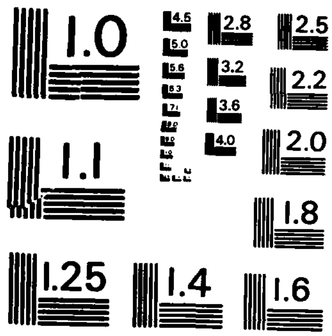

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INVESTIGATION OF EDDY CURRENT TECHNIQUES FOR THE INSPECTION OF GUN TUBE BORE EVACUATOR HOLES

ALFRED LANDMAN

MATERIALS TESTING AND EVALUATION DIVISION

February 1986

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ABSTRACT

A commercially built multiple-frequency eddy currect system, with several commercially available bolt-hole probes, was used to detect EDM slots in a section of 120-mm gun tube in which holes were drilled to simulate bore evacuator holes. The experiments performed demonstrated the possibility of slot or crack detection with these defects originating at the hole-surface interface. However, defect characterization and inspection by this method does not appear feasible.

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INTRODUCTION

A critical inspection area on the 105-mm M68, 120-mm XM256 gun, and other thick-walled cannon tubes is the bore evacuator holes. A "critical crack" can develop in the area of the bore evacuator hole. Present inspection procedures for production and in-service inspection of the entire tube utilize visual and magnetic flux leakage (magnetic particle and magnetic recording borescope) inspection techniques. The present inspection procedures possess a number of shortcomings: the magnetic particle indications are difficult to see in the bore evacuator hole, the magnetic recording borescope can inspect only the interior surface of the gun tube, proper magnetic particle inspection requires two magnetization orientations, the interior of the bore evacuator holes are difficult to observe visually, and the only quantitative information available is of surface crack length. An inspection procedure providing more quantitative crack information and ease of use for both production line and during lifetime inspection is required. Development of such an inspection procedure is also a requirement of future attempts to permit semiautomatic to completely automatic inspection of cannon tubes during manufacture.

The proposed approach for accomplishing this goal is the use of eddy current instrumentation with commercial bolt-hole probes of appropriate diameter that can be inserted from the outside and rotated at the hole bore intersection.

The procedure is straightforward and can be quickly performed. However, a complication in carrying out this procedure is the 30-degree angle between the evacuator holes and the tube axis. This geometrical fact results in the evacuator holes being elliptical at the bore surface. Thus, the center of the sensor part of the probe does not remain at the bore-surface interface if the probe is simply rotated. A fixture is required to maintain sensor surface alignment.

TEST PRINCIPLES

Eddy current nondestructive testing is used for metals to perform a variety of measuring, sorting, and flaw detection functions. Eddy current tests are indirect. For the gun tube test specimen, eddy currents are caused to flow by applying A.C. magnetic fields from an induction coil inside the probe. This flow of currents is affected by the presence of discontinuities or defects. In turn, the current flow makes its effect observable by affecting the electrical impedance of the exciting coil within the probe. Thus, the gun tube test specimen effects may be observed by monitoring the test probe impedance. The signal response is a weighted function, depending on the probe design, the operating frequency or frequencies, and the test specimen.

Eddy current instrumentation with both absolute and differential probes may be utilized in eliminating unwanted signals due to various parameters by increasing the number of frequencies used in various inspection applications.[1]

The test requirements dictate the optimal signal combination to be selected. As Reference 1 cautions, the potential combinations of frequencies to cancel one or more parameters is high and computer optimization techniques are

1. DAVIS, T. J. *Multifrequency Eddy Current Inspection with Continuous Wave Methods.* ARPA/AFML, Review of Progress in Quantitative NDE, LaJolla, CA, July 1978.

sometimes needed to obtain the appropriate magnitude of the desired indications relative to the parameters to be partially or completely eliminated from the combination output.

In the application considered, a probe containing a sensing coil or set of coils should be maintained perpendicular to an unwanted source of signal, namely, the bore-hole interface. This requirement necessitates the use of a fixture. The probe can then be rotated within the hole and the sensor will maintain alignment with the bore-surface interface.

In principle, the bore-hole interface signal can be eliminated, as can the effect of the wobble of the probe within the hole. Even if these cannot be totally cancelled by appropriate selection of frequencies and phase combinations, their appearance on the complex impedance plane should be distinguishable from a signal produced by the presence of slots or cracks.

Calibration data are available in the case of steam generator tubing inspection,[1] and a number of approaches are available to separate the wobble signals and the support plate signals (analogous to the bore-hole interface signals in the present inspection system).

The instrumentation that has been utilized for our study is a commercially built multiple frequency eddy current testing system, together with several commercially available bolt-hole probes. The selection of frequencies and combinations was made in a semiempirical fashion. The choice of probe limits the frequency range to be considered, and the combination of the two frequencies to be selected was made in accordance with the suggestions of Davis.[1] Frequency combinations other than those having a two-to-one ratio were tried, but no better results were obtained. The instrumentation does possess the capability to use up to four separate frequencies.

The method of combining the phases and amplitudes of the signals from each of the channels used (corresponding to the two frequencies selected) is determined by settings within the instrumentation system. The system can add the amplitude components and rotate the phases of the input signals in a mixer. A third frequency can give additional flexibility, but this was not utilized because the problems encountered cannot be resolved simply by introducing this added capability. Basically, the wobble signal and the signal produced when the probe leaves the elliptical path are larger and mostly in phase with the slot signal. Thus, the slot signal can be detected, however, the slot cannot be characterized with any confidence quantitatively even when optimum cancellation of the unwanted signals is achieved.

Improved determination of test conditions and settings might prove helpful, but only if the probe clearance within the hole can be maintained within limits and if the fixture design can be improved. The presence of slots or cracks, upon rotation of the probe, must lead to signals that are appreciably larger than, or essentially at right angles to, the unwanted signals.

EXPERIMENTAL SETUP AND TESTS

Test specimens were prepared to include bore evacuator holes, simulating those that exist in smooth bore gun tubes. EDM slots were introduced, simulating crack conditions in an idealized way.

Fabrication of the bore evacuator hole specimens was achieved by drilling holes in a 120-mm gun tube section (8" length) at four locations sufficiently spaced to eliminate eddy current interaction effects (Figure 1). Hole diameter and angle to the tube axis are in accordance with drawing no. 11579696 provided by Watervliet Arsenal. As noted before, because of the 30° angle with the tube axis, each evacuator hole is elliptical at the bore surface (Figure 2).

To establish detectability limits and to initiate the study on the characterization of cracks for location, depth, and width, EDM slots were machined at three hole-bore intersections. These were one forward longitudinal slot, one aft longitudinal slot, and one circumferential slot. The fourth hole, without slot, was intended for use in establishing baseline measurements in an attempt to suppress eddy current edge effects as the probe emerged at the bore surface.

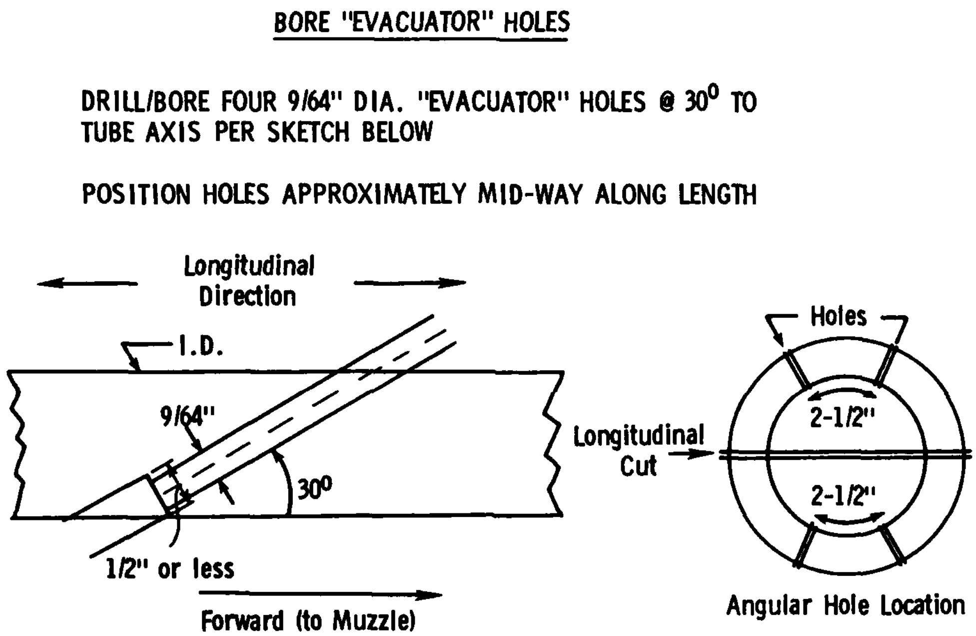

Figure 1. Require one EDM slot at corner of 3 holes: 0.005" wide, 1/8" long, 0.010" deep. Two slots in longitudinal direction (one forward, one aft) and one in curcumferential direction.

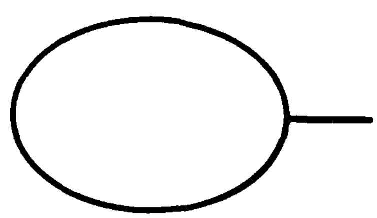

Figure 2. Hole at inside surface and longitudinal slot.

Tests were performed using both an absolute probe and a differential probe for single frequencies ranging from 50 kHz to 500 kHz. Later experiments included the use of two frequencies within this range.

Experimental procedures were first studied utilizing a geometrically simple test specimen; a rectangular plate with one hole drilled in the center, normal to the plate surface, with a slot extending from one edge to the opposite edge and perpendicular to both (Figure 3).

After the procedures were set, the same experiments were performed on the 8" length of 120-mm gun tube, cut into two halves, each piece with two bore evacuator holes drilled as discussed earlier. All holes were machined using a 9/64"-diameter drill bit.

Two commercial 0.140"-diameter probes (one absolute and one differential) were used. These were machined so that they would fit through the hole in the rectangular plate and all four holes in the two-halved gun tube pieces. Problems with the use of the probes became apparent soon after the experiments were initiated. Each probe was radiographed to determine sensor location, and to indicate any potential areas of difficulty.

For both probes, the probe diameter varied over the length inserted into the holes. More significnat were the variations of hole diameter (estimated at greater than 1 mil for some of the holes) and the nonlinearity of the hole center toward the inside of the gun tube. Since the inside of the gun tube is chromeplated, the drilling difficulties encountered as the chromium was drilled might have resulted in this noncylindrical shape of the hole.

In the experimental work, the probe wobble and the nonlinear nature of the hole, as well as the elliptical interface at which the probes rotation had to be made, resulted in large variations in unwanted signals for the differential probe. The absolute probe, for which an x-ray photograph is shown in Figure 4, proved more consistent, and was utilized for the results given below. Both probes gave adequate results for the rectangular plate test specimen.

Figure 3. Test plate with hole drilled in center, normal to plate center, with slot from one edge to the other.

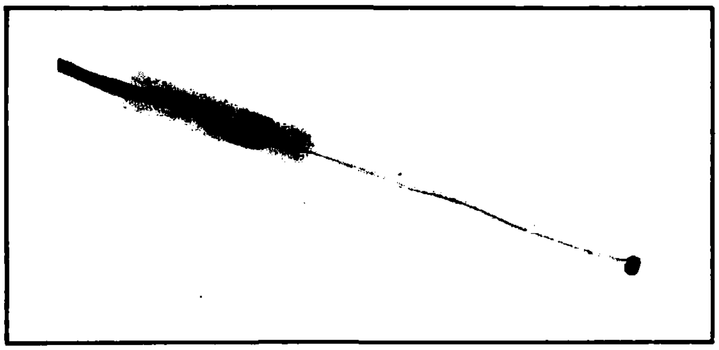

Figure 4. X-ray photograph of absolute probe.

A fixture to hold the probe firmly in the bore evacuator holes during rotation was then considered. Conceptually, the fixture is meant to permit the sensor center to be maintained at the interface of hole and gun tube inner surface. The material that appeared to have been suitable, and that was used, was hard nylon.

After the fixture was designed, fabricated, and introduced into the experimental setup, the above problems were reduced in severity, but not eliminated. The major difficulties remained when the probe was rotated over angles greater than a few degrees, especially with the interface at or near the long sides of the ellipse. A pivot point about which the fixture was to be rotated over 360° could not be maintained consistently. It was not possible to execute simultaneous rotational and in-and-out motion of the probe in the smooth manner necessary to keep the probe sensor center at the edge throughout the experiments.

RESULTS

Single frequency experiments on the eddy current instrumentation gave limited data. Although indicating slot signals, the edge effects and wobble significantly interfered with slot detection. This held true for the gun tube experiments, even for the case of the slot position in the aft direction of the gun tube, for which the slot signal indications were strongest.

Good results were obtained for the rectangular plate utilizing two frequencies. This probe-plate geometry, with the hole drilled normal to the flat plate and the two slots separated by 180° at the hole-surface interface, gave good indications for both absolute and differential probes. For the differential probe, the eddy current signal appeared as an extremum in the bridge circuit, then an effective null, and then another extremum, during rotation in the slot vicinity from one side of the slot to the other.

For multiple-frequency operation experiments with the bore evacuator holes of the gun tubes, a two-to-one ratio of frequencies (400 kHz and 200 kHz) gave the best results. Two channels were used and the outputs combined appropriately in the mixer. The slot signals with the absolute 0.140"-diameter probe were the only ones that could be considered useful for effective results. Although optimization of the instrumentation settings did not eliminate the unwanted signals, they were reduced.

When inserting the probe, output signals were observed on the storage oscilloscope with the reference point (instrumentation balanced to null signal) selected with the probe center at the interface of the hole and gun bore surface at the slot initiation site on the ellipse. The test trace was obtained by rotating the probe ±15° from this reference point for the hole without slot; the oscilloscope brightness was then turned down, and the superimposed trace signal was obtained with an equivalent rotation around the reference point for the hole with slot. A Polaroid picture of the superimposed oscilloscope traces was then taken for all such tests performed.

Differential signal shapes ("signatures") were obtained for the three-slot orientations with the strongest and most clearly defined for the slot position in the aft direction from the bore hole (Figure 5). A horseshoe-shaped signal was obtained (Figure 6), for the slot in the opposite direction. For the circumferential slot, it was difficult to obtain a "signature" perpendicular to the unwanted signal. The largest effective signal strength, or ratio of slot signal to unwanted signal, equal to two, was obtained with an angle of about 45° between the two signals (Figure 7). The results varied appreciably over a series of tests, because of the problems encountered in moving the probe appropriately along the long edge of the ellipse.

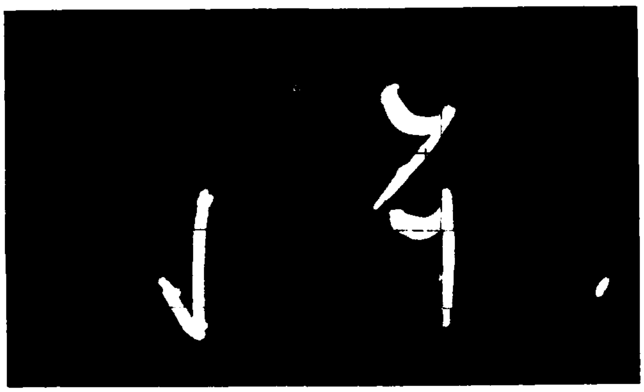

Figure 5. Signal for slot position in the aft direction from the bore hole.

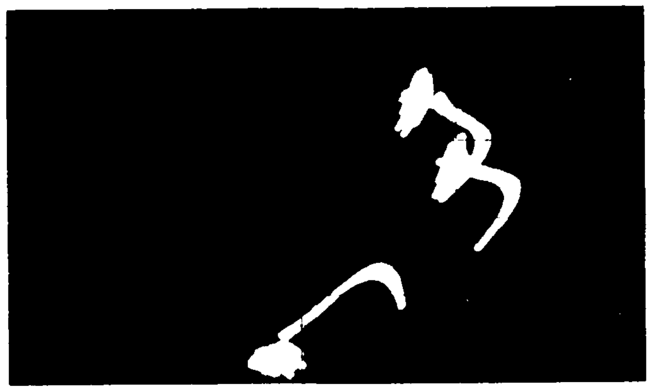

Figure 6. Signal for slot position in the forward direction from the bore hole.

Figure 7. Signal for circumferential slot.

DISCUSSION

Confidence in the validity of the experimental results is good, in the sense that the results were reproducible.

Initial results with the flat plate were qualitatively as expected. This probe-plate geometry was adequate for easy detection by both absolute and differential probes. For the plate, the tests could probably have been extended easily to experiments for simple slot and crack characterization. This was not done, however, because our interest is in the gun tube evacuator holes and adjacent inside surface.

For the bore evacuator holes, the results that are most straightforward to use are those in which the desired signal is perpendicular to the unwanted signals. Results in which the impedance plane defect signal is at angles other than 90° with the unwanted signals may still be useful, however. In the case of the aft longitudinal slot, especially, the strong signal displayed in Figure 5 is indicative of what might be expected, since the choice of freqencies and the partial cancellation of unwanted signal leads to good, reproducible oscilloscope trace signals. In implementation for detection and characaterization of cracks in the vicinity of the bore evacuator holes, optimum signals would, of course, occur at 90° to any undesired ones, since no ambiguity could remain as to edge or wobble effects and crack signals. Presently, this appears difficult to attain, if the magnitude of the crack signal is to be two or more times that of the unwanted signals.

Detectability of the slots in our test specimens was good. However, if slots or cracks were present that were somewhat smaller, problems in detecting them would occur. Also, slot depth and width would not be quantitatively determined by insertion and rotation of the probe in a gun tube in an unknown situation. From what has been learned in the tests and experimental work, it would be difficult to set a threshold for a crack size to be detected.

For larger frequency ratios than two, a greater separation of desired and unwanted signals can be obtained for the aft longitudinal slot. However, because of the greater curvature differences for the two frequencies on the impedance plane, the resultant signal in the mixer for the slot is more complex and the unwanted signals are even less susceptible to cancellation.

For the forward longitudinal slot, and the two-to-one frequency ratio, the horseshoe-shaped signature appears to have been due to a superposition of defect (slot) and edge effect signals. The probe rotation in the hole with the slot was more difficult to execute than in the hole without the slot, and the fixture helped only slightly. The drilled hole with the forward longitudinal slot appeared to have been the most noncylindrical, and this may have contributed significantly to the signal shape. However, the repeatability of the trace signals, all of which appear similar to Figure 6, leads to the conclusion that a forward longitudinal slot gives different indications on the eddy current plane than an aft longitudinal slot.

For the circumferential slot, obtaining a "signature" perpendicular to the unwanted signal was not achieved. In addition, the slot signal could not be obtained as strong as the unwanted signals under conditions tried with the two-frequency system used. Among the best results obtained is the one shown in Figure 7. For this slot location, making meaningful measurements is very difficult. The fixture is essentially of no help because play permitted by it gives large signals as the probe is rotated.

CONCLUSION

The results for the eddy current investigation of bore evacuator holes are repeatable and reproducible. However, an inspection procedure cannot be formulated at this time. From the results presented here, it is difficult to predict slot orientation and even more significantly slot depth and width (crack simulation) by inserting the probe in an unknown situation.

The geometry of the bore evacuator holes presents difficulties for detecting and characterizing cracks. The effect of rifling for gun tubes (present in those other than the smooth bore 120-mm tube) will undoubtedly lead to additional complications.

It is concluded that eddy current inspection procedures for crack determination adjacent to bore evacuator holes, in particular for 105-mm and 120-mm gun tubes, may be feasible. It will require more elaborate experiments, designs, and systems studies.

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Key Words

Nondestructive testing
Eddy currents
Gun tubes

A commercially built multiple-frequency eddy current system, with several commercially available bolt-hole probes, was used to detect EDM slots in a section of 120-mm gun tube in which holes were drilled to simulate bore evacuator holes. The experiments performed demonstrated the possibility of slot or crack detection with these defects originating at the hole-surface interface. However, defect characterization and inspection by this method does not appear feasible.

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